The Mars Atmosphere Trace Molecule Occultation Spectrometer

Geoffrey C. Toon[1], Paul O. Wennberg[2], Victoria J. Hipkin[3], James R. Drummond[4]

[1] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, USA
[2] California Institute of Technology, Pasadena, USA
[3] Canadian Space Agency, Quebec, Canada
[4] Dalhousie University, Nova Scotia, Canada

Abstract: The Mars Atmosphere Trace Molecule Occultation Spectrometer (MATMOS) FTS is described, with emphasis on the data acquisition and on-board data processing.

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1. Introduction.

The proposed 2016 ESA/NASA ExoMars mission consists of the Trace Gas Orbiter (EMTGO) and an entry demonstration lander [1]. EMTGO would carry five remote sensing experiments that would study the Martian surface and atmosphere. One of the five orbiting experiments planned is MATMOS, a solar occultation FTS combined with an imager. The MATMOS FTS would analyze the trace gas composition of the Martian atmosphere, improving the detection sensitivities of many gases by 2-3 orders of magnitude. Of particular interest are trace gases diagnostic of biogenic (e.g. CH_4) or volcanic (e.g. SO_2) activity.

The MATMOS Science Team is led by Paul Wennberg (PI, California Institute of Technology) and Victoria Hipkin (Co-PI, Canadian Space Agency (CSA)). It combines key member of the FTS community with planetary and terrestrial atmospheric scientists. The project is managed by NASA's Jet Propulsion Laboratory, where the instrument would be assembled. ABB-Bomem is the prime contractor for the FTS interferometer sub-system and the imager, which are a CSA contribution to the instrument.

2. Science Goals.

The proposed MATMOS investigation would:
- Determine the origin of trace gases diagnostic of active geological and biogenic activity.
- Quantify the lifetimes of these diagnostic gases in the context of the atmospheric state.
- Provide definitive detections and essential support for the TGO localization effort
- Determine the sources, lifetime and sinks of Mars methane

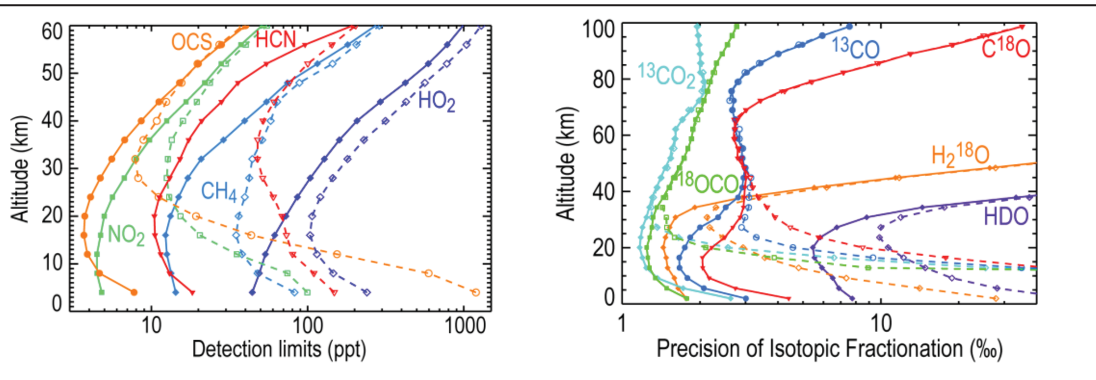

Figure 1. Estimated MATMOS sensitivity to various gases in the Martian atmosphere under clear (solid lines) and dusty (dashed lines) conditions. Left panel shows estimated gas profile sensitivities in part per trillion. Right panel shows isotopic fractionations in parts per mil (‰).

MATMOS would detect, profile, and map with parts per trillion (ppt) sensitivity many trace gases. Estimated sensitivity profiles of a few gases and isotopologs are shown in Figure 1.

3. The MATMOS Instrument.

MATMOS is a solar-occultation FTS with heritage from the ATMOS instrument that flew on four Space Shuttle missions (1985-1994) [2], the JPL MkIV balloon interferometer that has performed 22 balloon flights since 1989 [3], and the ACE-FTS that has been flying on the Canadian Scisat satellite since 2003 [4]. Aboard EMTGO MATMOS would measure the transmittance of the Mars atmosphere using the Sun as a source. Twice per orbit, as the spacecraft enters and emerges from the shadow of Mars, MATMOS would acquire infrared spectra of sunlight at

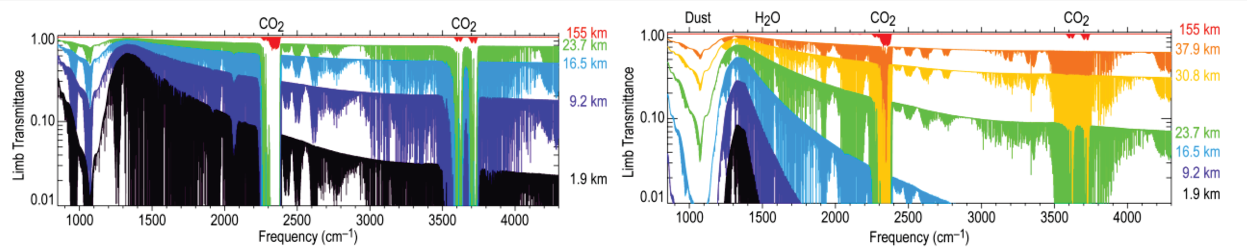

Figure 2. Simulated infrared Martian spectra for low dust conditions (Left: τ=0.1) and high dust conditions (Right: τ=0.1). Colors represent simulated Mars spectra from 1.9 km (black) to 155 km (red). The spectrally broad extinction is due to cloud and dust while gases produce dense progressions of discrete absorption lines.

different tangent heights. The concentration of various atmospheric constituents can be retrieved from the limb transmittance spectra, simulated examples of which are shown in Figure 2. Because of the high radiance from the Sun, the instrument can measure a broad spectral region (850-4320 cm^{-1}) with a fine spectral resolution (0.02 cm^{-1}) and high signal to noise ratio (> 250:1). The instrument would acquire approximately 70 spectra per occultation over 0 to 200 km altitude.

The MATMOS FTS optics are very similar to those of ACE, with some small improvements based on GOSAT heritage. A separate presentation [5] will describe the MATMOS interferometer sub-system and imager. MATMOS would use two photodiode detectors simultaneously: HgCdTe covering 800-1900 cm^{-1}, and InSb covering 1850-4320 cm^{-1}. These would be cooled to 90K by a passive cryocooler, of a similar design to that used by ACE.

Although MATMOS derives strong heritage from ACE, especially in the interferometer sub-system and imager, there are some notable differences:

1) Data telemetry limitations necessitate extensive on-board processing and variable scan speed
2) Atmospheric dust layers requires correction for solar intensity variations
3) High dynamic range requires 24-bit ADC (to avoid gain switching) and hence uniform time sampling
4) Spacecraft performs pointing (no suntracker).

These differences are the main focus of the remainder of this presentation.

Some of the differences between ACE and MATMOS are forced by the low data telemetry rate between Mars and Earth. With only 1.9 Gbit/day available to MATMOS, it would be necessary to convert interferograms into spectra inside the MATMOS instrument. Fortunately, the duty cycle of the MATMOS instrument is only 5-10%, so this conversion could be done during the time between occultations, when MATMOS would not be acquiring new data.

The raw time-domain interferograms are first re-sampled onto a grid that is uniform in optical path difference, using the metrology laser interferogram. The interferograms are also corrected for solar intensity variation, using the DC interferogram signals. They are then phase corrected and FFT'd inside the MATMOS instrument. Parts of the spectra

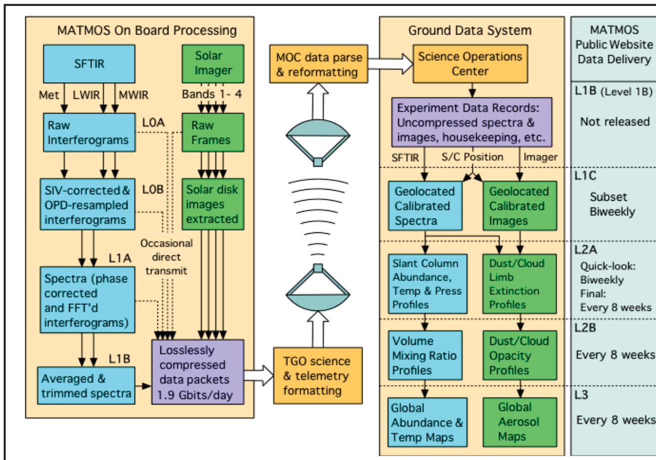

Figure 3. Conversion of interferograms into spectra takes place in the MATMOS instrument (left). Analysis of spectra into atmospheric composition profiles (right) takes place on Earth.

containing little useful information are discarded. Calibration spectra are also derived from high sun and deep space spectra. Finally, the remaining spectra are losslessly compressed, before being transferred to the spacecraft for telemetry back to Earth. Two RAD-750 single board computers would perform this on-board processing. Figure 3 illustrates the processing of FTS and imager data in the MATMOS instrument (left) and and on Earth (right).

The Mars atmosphere is often laden with dust, which can considerably attenuate the solar signal. This is especially severe near the Martian surface where the limb optical depths can far exceed unity, especially at short wavelengths. Since some of the most interesting and short-lived atmospheric gases are expected to be close to the Mars surface, it is important that MATMOS be designed to minimize the effects of dust. The dust extinction not only degrades the signal-to-noise ratio, but vertical structure in the dust can cause (wavelength-dependent) modulation of the solar signal that is fast compared with interferogram acquisition times (2 to 6 s). If not corrected or accounted for, these source brightness fluctuations would deform the instrument lineshape (ILS) and hence corrupt the gas profile retrievals. To help deal with this, MATMOS would record the DC signal levels for each IR detector and use this information to correct the spectra. It would also have a boresight-aligned four-band imager to detect layering of the dust within and around the field-of-view.

To avoid gain switching during interferogram acquisition, MATMOS would use a 24-bit ADC of the Sigma Delta type which requires uniform time sampling of the interferograms. A major effort is underway at JPL to flight qualify the candidate device for MATMOS. Tests already performed to measure the Total Ionizing Dose (TID) and Single Event Upsets (SEU) are encouraging.

MATMOS would not have an active suntracking capability. Instead, it would rely on the spacecraft to remain pointed (within 0.5 mrad) at the geometric center of the solar disk using the star tracker. The absence of significant refraction by the Martian atmosphere makes this feasible. Geometric pointing has the advantage over radiometric pointing (i.e., using a quadrant detector like ACE) that the solar tracking is not perturbed by dust layers in the Martian atmosphere and keeps pointing at the same spot on the solar disk throughout the occultation, minimizing variations in the solar spectrum due to the inhomgeneity of the solar disk (sunspots, limb-darkening, rotational doppler shift).

4. Conclusions.

The MATMOS interferometer, fore optics, and cryo-cooler are based on ACE heritage. The signal processing electronics are based on newer devices (24-bit ADC, RAD-750) and techniques (Uniform Time Sampling, correction of solar intensity variations). This combination of flight-proven heritage and new technology promises a new and unique view of the Martian atmosphere and its composition. The wide and continuous spectral coverage would permit many studies of gases that we know are present in the Martian atmosphere, but would also provide data for the potential detection of gases whose presence we do not suspect at the present time. These measurements and the studies that they engender would significantly advance our understanding of the Martian atmosphere and planetary system.

5. Acknowledgements.

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6. References

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